Examensarbete
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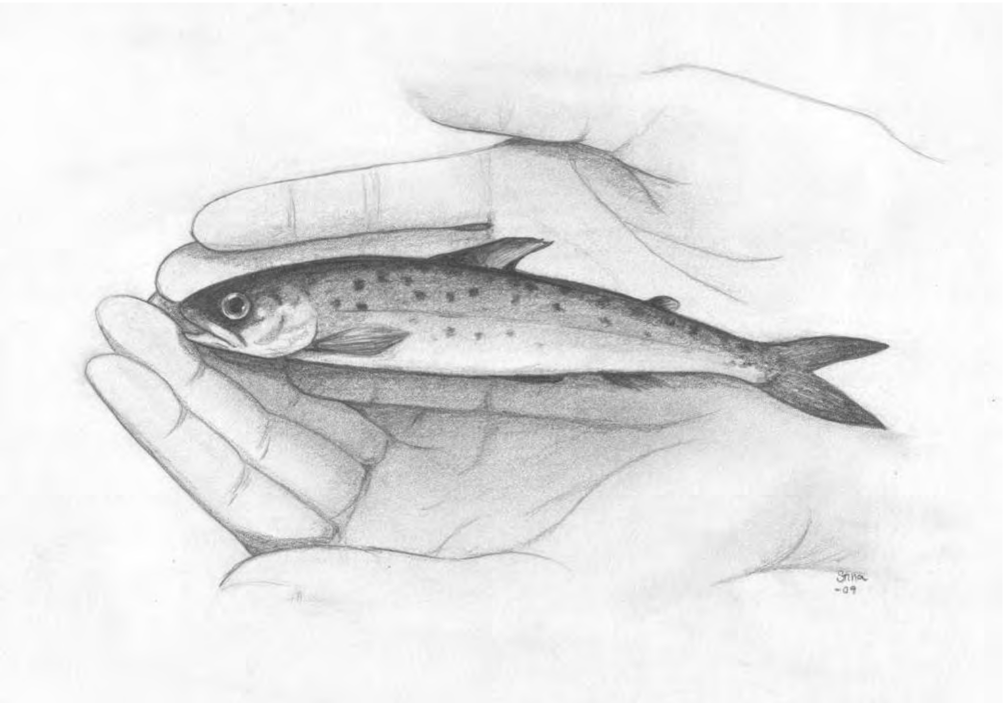
Migration losses of Atlantic salmon (*Salmo salar* L.) smolts at a hydropower station area in River Åbyälven, Northern Sweden

-Passage fates at a reservoir, a power house and a bypass structure

Stina Gustafsson



Sveriges lantbruksuniversitet
Fakulteten för skogsvetenskap
Institutionen för vilt, fisk och miljö
Examensarbete i biologi, 30 hp, D-nivå

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Lax (Salmo salar L.) smoltmortalitet orsakad av passage genom ett vattenkraftverksområde i Åbyälven, norra Sverige

-En jämförelse mellan mortalitet i en damm, en turbin och i en fisktrappa

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Keywords: Radio-transmitter, Tracking, Telemetry, Mortality, Loss rate, Turbine, Fishway

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ABSTRACT

Stina Gustafsson. 2010. Migration losses of Atlantic salmon (*Salmo salar* L.) smolts at a hydropower station area in River Åbyälven, Northern Sweden. -Passage fates at a reservoir, a power house and a bypass structure. MSc-thesis, 30 ETC. Department of Wildlife, Fish, and Environmental studies, SLU, SE-901 83, Umeå, Sweden.

A large number of rivers in northern Sweden have hydropower developments that cause negative effects on both up- and downstream migrations of anadromous species like Atlantic salmon. So far, most attention has focused on the hindrances of adult fish during their upstream spawning migration. However, since turbines in power stations cause losses on downstream passing fish, the focus on negative effects on smolts has increased. The aim of this study was to compare three different causes of losses of salmon smolts passing downstream through a power station area in the flow-controlled River Åbyälven in northern Sweden.

A total of 61 wild salmon smolts were caught and radio-tagged in the River Åbyälven during their downstream migration in June 2009. The salmon smolts were released at three locations, 1.1 km upstream from the power station, in the turbine intake and in the upper part of a fishway, acting both for up- and downstream fish passage. In this study, 59% of the radio-tagged smolts released upstream from the power station remained stationary close to their release location during the entire study period. It is believed that most of these smolts became victims of predation. About 35% of the radio tagged smolts that descended downstream via the turbine were judged as dead after passage, whereas the losses of smolts passing downstream through the fishway was 33% (explained by lethal injuries). The overall mortality of smolts passing the power station reservoir, the turbine and the fishway in the river was estimated to be about 94%.

Taking these results into account, the dammed up area with its predators, seems to be what poses the greatest threat to the smolts during their downstream migration.
The mortality during passage through the fishway and the mortality during passage through the turbine showed little difference. It seems that it is almost as dangerous for the smolts to take the route through the fishway as to take the route through the turbine.

Keywords:
Radio-transmitter, Tracking, Telemetry, Mortality, Loss rate, Turbine, Fishway

SVENSK SAMMANFATTNING

Stina Gustafsson. 2010. Lax (*Salmo salar* L.) smoltmortalitet orsakad av passage genom ett vattenkraftverksområde i Åbyälven, norra Sverige. -En jämförelse mellan mortalitet i en damm, en turbin och i en fisktrappa Examensarbete 30hp. Ht-2009. Institutionen för Vilt, Fisk och Miljö, Sveriges Lansbruksuniversitet (SLU), 901 93 Umeå.

Ett stort antal älvar i norra Sverige är utbyggda för vattenkraft, vilket medför stora problem vid upp- och nedströmsvandring av anadroma arter, till exempel lax. De flesta studier som gjorts på vandrande lax har fokuserat på uppströmsvandring av vuxna fiskar, men under senare år har även fokus lagts på nedströmsvandring av smolt.
Syftet med denna studie var att undersöka mortaliteten av smolt orsakad av passage genom ett vattenkraftverksområde i Åbyälven och jämföra dödligheten hos märkt laxsmolt efter utsättning i ett uppströmsliggande dammområde, i inloppskanalen till en turbin och via direkt frisläppning i en fisktrappa.

Totalt 61 vilda laxsmolt fångades och märktes med radiosändare i Åbyälven under vandringsperioden (4 juni - 12 juni) 2009. Dessa laxsmolt släpptes ut på tre olika platser, 1.1 km uppströms kraftverket, bakom rensgallret och i övre delen av fisktrappan.
I denna studie stannade 59 % av de smolt som släppts ovan kraftstationen i närheten av utsättningsplatsen under hela vandringsperioden. En stor del av dessa smolt antogs ha blivit offer för predation. 35 % av de radiomärkta fiskarna som simmat genom turbinerna antogs ha dött vid turbinpassagen, medan mortaliteten för smolt som simmat genom fisktrappan uppgick till 33 %. Den totala mortaliteten orsakad av passage genom det dämda området, turbinerna och fisktrappan i Åbyälven uppgick till ca 94 %.

Dessa resultat visar att den dämda delen av älven ovan kraftstationen verkar vara det mest riskabla området som laxsmolt måste passera på sin väg ner till havet.
Skillnaden i mortalitet via turbinpassage och via passage genom fisktrappan var marginell, vilket innebär att det är nästan lika farligt för laxsmolten att vandra genom fisktrappan som att vandra via turbinen.

INTRODUCTION

Hydropower development usually provides economic benefits but at the same time have negative impact on river ecosystems (Reyes-Gavilán *et al.* 1996). River regulations have harmful effects on migratory fish species, both on an individual and on a population level (Rivinoja 2005). In northern Sweden numerous rivers are regulated for hydropower, still some of these have wild salmon reproduction at upriver areas, and consequently fish have to pass both up- and downstream during their lifetime to sustain their population. Nevertheless, in many European countries most attention has been focused on adult fish during their upstream spawning migration. This applies to both scientific publications and to actual actions taken in order to facilitate the upstream migration of spawning adults (Calles 2006). However, during the last decade the focus on negative mortality effects on downstream migrating smolts has increased when they pass through: 1) reservoirs, mainly caused by predation and stress during passages of the dammed sections, 2) power houses, i.e. passage through turbines and tunnels, and 3) spillways or specially designed bypasses. Generally, the first obstacle that the smolts face during their downstream migration in a regulated river is found at dammed reservoirs. These sections of slow flowing water tend to favour piscivorous species which cause high mortality on smolts by predation (Hvidsten & Johnsen 1997). These lentic areas may also slow down the migration which leads to a postponed migration period (Mathers *et al.* 2002).

Commonly the mortality reasons on downstream migrating fish at power station areas can be separated into direct and indirect mortality components. The direct mortality that causes instant death is generally related to mechanical damages, while the indirect mortality weakens or injure the fish which may lead to delayed mortality. Usually the loss rate is highest for fish passing downstream via turbines, while high survival can be achieved via specially constructed downstream bypasses. Spillways may also cause direct or indirect mortality due to shearing forces, turbulence, variations in velocity and pressure, mechanical injuries from hitting spillway constructions and increased susceptibility to predation due to stunning after the fall (Coutant & Whitney 2000).

The aim of this study was to compare three different types of losses of salmon smolts passing downstream through a power station area in the regulated River Åbyälven in northern Sweden. The three kinds of losses were separated into passages through; 1) a reservoir, 2) a power house, and 3) a fishway acting as a downstream bypass. Besides this, various studies dealing with power station induced mortalities in Swedish rivers were reviewed.

BACKGROUND – Power station mortalities on smolt

Different hypothesis, concerning the natural migration behaviour pattern of smolt, have been made. Some state that the fish show passive behaviour and follow the water movement (Moser et al.1991 & Pirhonen *et al.* 1998), while others have observed active downstream swimming of smolt (Fängstam 1993, Dempson & Stansbury 1991 & Giorgi *et al.* 1997). Nevertheless, active or passive, most smolts seem to follow the main flow in the highest water velocities, perhaps in an attempt to minimize the predator pressure (Ruggles 1980). In many rivers exploited for hydropower, the main part of the river is led through the turbines. Consequently, depending on flow patterns, the smolts will likely be guided towards the turbines that can cause mortality on passing fish.

In Sweden the two most common turbine types used in smaller hydropower stations are Francis and Kaplan (Jonsson *et al*. 2003). Available studies (summarised in Table 1) suggest that Kaplan turbines seem to be less harmful to the fish than Francis turbines (Montén 1985), mainly due to the higher number of blades per runner in the Francis turbines. Usually, the Francis turbines have 10-20 blades, compared to the Kaplan turbines that normally only have 4-8 blades (Jonsson *et al*. 2003). The mechanical damages for fish passing power houses are attributive to the turbine blades and can be estimated by blade-strike modelling (Ferguson 2008). The blade strike injuries may be severe with damages to the body, the internal organs and skeletal components, which almost always lead to an instant death. The fish may also suffer non-fatal injuries such as stunning and loss of gills or eyes, causing an indirect mortality. Another danger that may threaten the fish during its passage is the huge drop in pressure in the region between the turbine's wicket gates and the exit of the turbine runner. This change in pressure can cause injuries to organs such as the swim bladder (Ferguson 2008) and lead to either an instant or a delayed mortality or temporary or permanent disability. The fish may also experience negative buoyancy when entering the tailrace (Ferguson 2008), which causes the fish to float until it is able to achieve equilibrium. This makes the fish highly susceptible to avian and piscine predation (Coutant & Whitney 2000). Other factors that may affect fish negatively in connection with the turbine passage are the loud noise, the shearing forces and the turbulence in the turbine which may affect the salmon's sensory system negatively so fish may experience difficulties to detect and avoid predators (Ferguson 2008).

Table 1. Loss rates (direct and indirect mortalities) for smolts passing turbines. Direct loss represents direct mortality caused by turbine passage, while the total loss corresponds to the combined direct and indirect mortality for all fish passing the turbines.

Reference	**River**	**Power station**	**Turbine**	**Flow (m^3s^{-1})**	**Species**	**Direct loss**	**Total loss**
This study	Åbyälven	Hednäs	Kaplan	10	Salmon	35%	96%
Calles et al. *In review*	Ätran	H1	Kaplan	39.1	Salmon	8%	10%
Calles et al. *In review*	Ätran	H2	Kaplan	39.1	Salmon	6%	10%
Rivinoja et al. 2005	Piteälven	Sikfors	Kaplan	200	Salmon/ Brown trout	12%	19%
Calles & Greenberg 2009	Emån	L. Finsjö	Kaplan	24.4	Brown trout	11%	34%
Engqvist 2008	Emån	L. Finsjö	Kaplan	17.4	Brown trout		31%
Montén 1985	Umeälven	Stornorrfors	Francis		Salmon	2.5-28%	25%
Serrano et al. 2009	Testeboån	Vävaren	Francis	10	Salmon	60-75%	
Palm et al. 2009	Sävarån	Sävarån	Francis	20	Salmon	0%	0%
Calles & Greenberg 2009	Emån	U. Finsjö	Francis	20	Brown trout	38%	36%
Engqvist 2008	Emån	U. Finsjö	Francis	17.4	Brown trout		68%

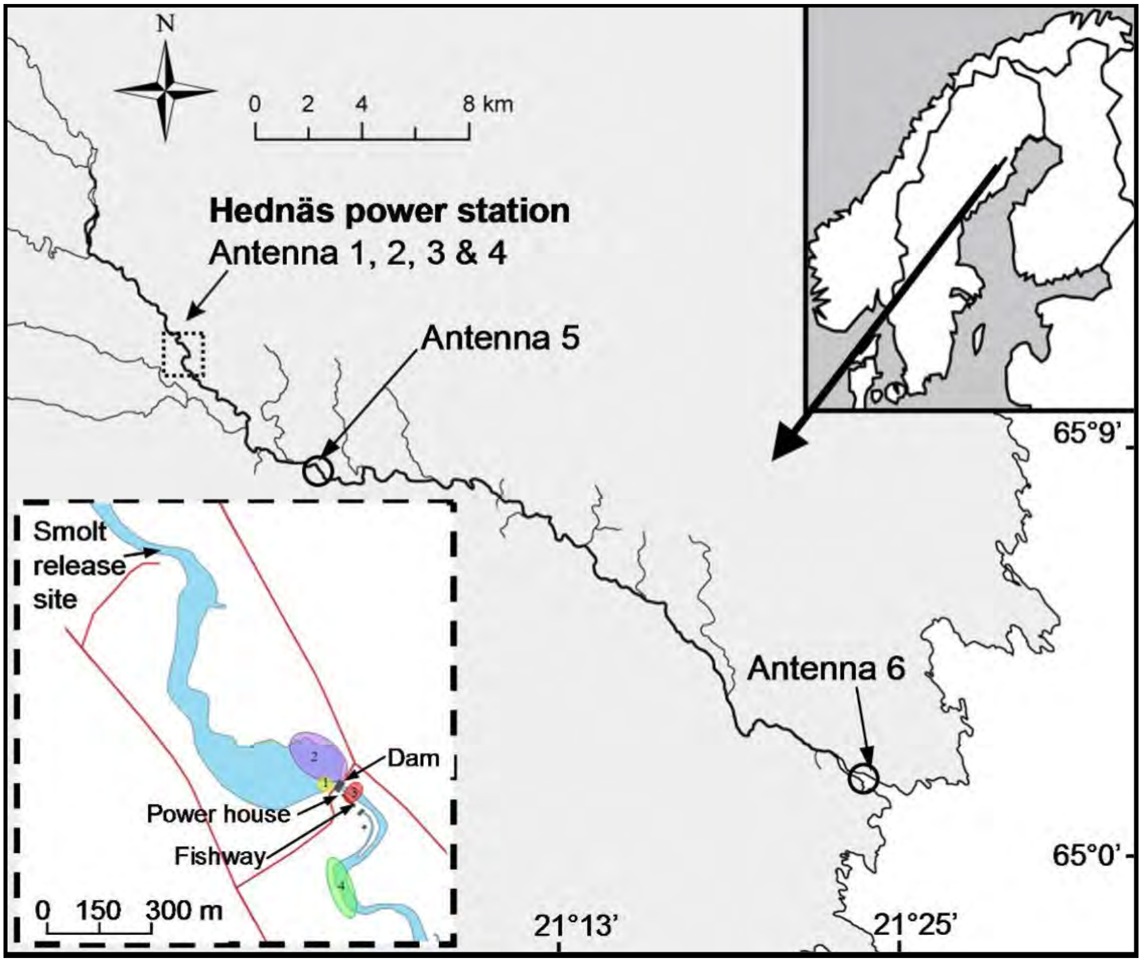

Figure 1. Location of River Åbyälven in northern Sweden with sites of the power station and telemetry-antennas (arrows) indicated. In the dashed square, smolt release site and antenna detection zones (shades surface with numbers) are shown.

METHODS

Study Area

River Åbyälven in northern Sweden flows through forests and wetlands in a south-easterly direction (Figure 1). The river is c. 230 km long and reaches the Bothnian Bay at 65°0'40''N, 21°24'55''E. The mean flow (MQ) is 10.4 m^3s^{-1}, with a highest water bearing (HQ) of 120 m^3s^{-1} and a lowest flow (LQ) of 0.5 m^3s^{-1} (data from SMHI, Swedish Meteorological and Hydrological Institute). Since 1919 the river is regulated by the hydropower station Hednäs about 30 km upstream from the coast, with re-constructions made in 1995. The power station is relatively small with a head of 15.5 m and, using a single Kaplan turbine, has a maximum effect of 2.15 MW (data from Skellefteå Kraft AB). In 1996 a fishway was assembled in the power station area to facilitate up- and downstream migration of salmon. The upper part of the fishway (c. 100 m) consists of a metal flume formerly used for timber floating with roughly 20 overfall weirs (c. 0.3 wide and 0.2 m deep), while the lower part (c. 50 m) is a concrete ladder type construction (overall ladder length of 150 m).

The Atlantic salmon and the smolt run in River Åbyälven

In northern Sweden, the adult Atlantic salmon generally begin their upstream migration in summer and finish their spawning in late autumn (McKinnell 1998). The eggs hatch about six months later and the offspring can spend several years in freshwater. After this they undergo a smoltification and migrate seaward, primarily initiated by increasing water temperatures and flows in the spring (Ferguson, 2005).

In River Åbyälven the riverine sections are predominated by Atlantic salmon (*Salmo salar*), sea trout (*Salmo trutta*) and European grayling (*Thymallus thymallus*), while Northern pike (*Esox lucius*), Eurasian perch (*Perca fluviatilis*) and whitefish (*Coregonus lavaretus*) are common in the lentic areas. Based on mark-recapture studies, the smolt run passing the power station area has been roughly estimated to 1100-9300 salmon smolts in the years 2003-2009 (Stridsman 2008). These smolts were generally three years old, typically ranging from 15-17 cm in length.

Water flow, temperature and stream velocity patterns

The ambient water temperature during the study period was measured with two OnSet-TidBit temperature loggers located at the power house intake. During the course of the study, the temperature increased from about 10.4°C to a peak of 20.5°C and during the tag and release event, the temperature ranged between 12.8-17.5°C (Figure 2). Three temperature drops were noted, where two drops occurred during the migration period of the tagged smolts.

The flow during the study ranged between 8-17 m^3s^{-1}, with 10-13 m^3s^{-1} noted at the tracking period of tagged smolts (data from Skellefteå Kraft AB). Based on aerial photographs and visual field mapping, the stream characteristics at various sections of the river were classified into four groups according to the method described by the Swedish Environmental Protection Agency (Naturvårdsverket 2003). These groups represented waters with; 1) slow flow (0.1 m s^{-1}, deep- and slow flowing water), slow riffle (0.25 m s^{-1}, no turbulence), fast riffle (0.5 m s^{-1}, turbulent water) and rapid (1.0 m s^{-1}, highly turbulent water). A total river-distance of 41 km was mapped, ranging from the release site of tagged smolts (1.1 km upstream from the Hednäs power station) downstream to the sea. The total transportation time for the water from the power station to the river mouth was estimated to c. 29 h, corresponding to an average stream velocity of 0.4 m s^{-1}.

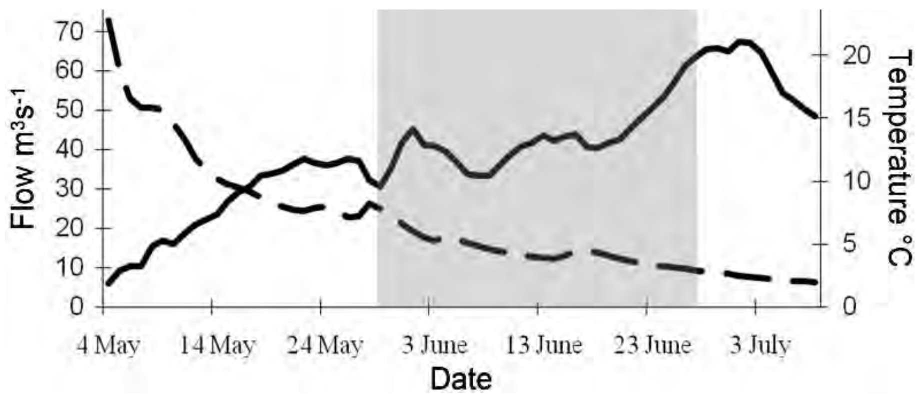

Fig. 2. Flow (broken lines) and temperature (solid lines) in Åbyälven, 4 th May - 8 th July. The grey area indicates the tracking period of smolts.

Radio-tagging and release of smolts

In 2009, wild downstream migrating salmon smolts were caught in a trap placed in the middle of the fishway (Figure 1). The downstream migration peak took place on the 1st of June at a temperature of 14 °C (Figure 4 & 5).The trap was emptied twice a day, once in the morning (c. 9:00 AM) and once in the evening (c. 6:00 PM). Length and weight of all tagged fish were recorded. Between 29 th May-17 th June a total of 334 smolts were caught in the trap, of which 61 were selected for radio tagging. All these individuals were considered to fulfil the criterion of being fully smoltified, indicating a slim body shape and silvery colourisation without red spots and dark stripes, and with transparent anal fins. At the tagging, the smolts were anaesthetized in MS 222 (Tricaine mesylate) before handling. The transmitters used were ATS F1510 (40 ppm), with a mass of 1.0 g and a battery life time of approximately three weeks. Since the weights of the transmitters are suggested not to exceed 5-6 % of the total fish mass (Adams *et al.* 1998) only smolts with a body length ranging between 151-194 mm (mean of 168 mm, representing an average mass of 34 g) were radio tagged. The transmitters were inserted in the body cavity, through a 10 mm incision in the belly and the antenna was protruding through a hole from the body cavity (Figure 3). The incision was closed with two sutures. The implantation of radio transmitters took place at the riverbank close to the trapping site. After radio tagging, the smolts were moved to a water tank and transported to the release site where they were placed in a holding tank in the river for c. 10 h for observation and recovery.

Releases of radio tagged smolt were conducted between 4th -12th June. In total, 30 of the tagged smolts were released 1.1 km upstream from the power station in two groups of 15 smolts together with 15 untagged smolts. The purpose of this release was to examine in which proportions the downstream migrating smolt would swim through the turbine and the fishway. Additionally, 15 of the tagged smolts were released in the turbine intake in three groups of five smolts with the purpose of examining the turbine induced mortality, while 13 tagged smolts were released in the fishway in three groups. The purpose of this release was to examine the migration success rate through the fishway. Three tagged smolts were euthanized and released in the turbine intake, with the aim to examine how far a smolt killed by the turbine could be expected to travel with the stream before it would sink.

Fig. 3. Placements of the surgically implanted radio-transmitters (redrawn from Hockersmith et al. 2000).

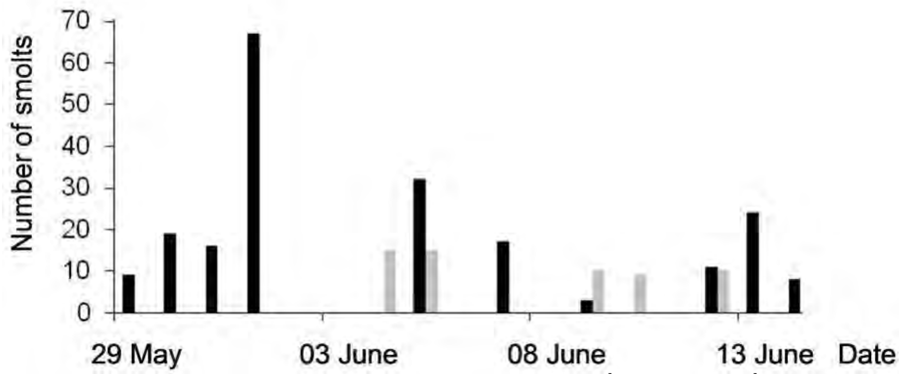

Fig.4. Number of smolt caught in Åbyälven 29 th May - 17 th June 2009. Black bars indicate the number of untagged smolt and grey bars indicate the number of tagged smolt.

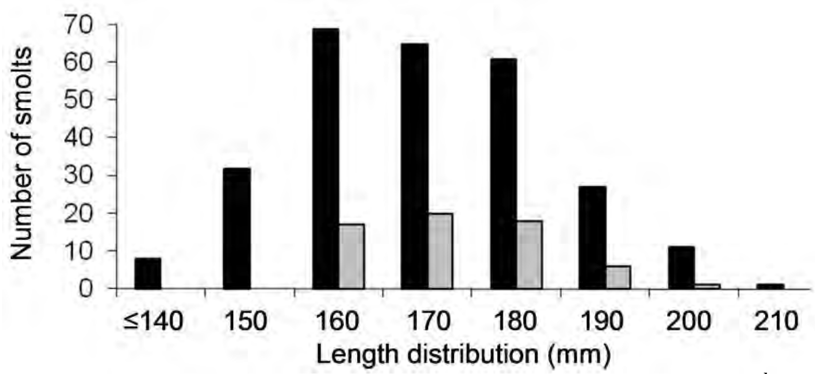

Fig.5. Length distribution of smolts caught in Åbyälven 29 th May - 17 th June 2009. Black bars indicate the size in lengths of untagged smolt and grey bars the lengths of the tagged smolt.

Telemetry tracking of fish

Five LOTEK SRX_400 loggers, one equipped with a switch-box allowing the use of totally six 4- and 9-elements Yagi antennas were placed along the river Åbyälven (Figure 1). The first antenna was placed upstream from the power station and covered the turbine intake (at a river distance of 42 940 m from the sea). The second antenna was placed next to the power station and covered the southern part of the dam, the turbine intake and the northern part of the fishway. The third antenna covered the spillway and the fishway (c. 42 900 m from the sea). The fourth antenna was placed downstream from the power station (at a river distance of 42 640 m from the sea) and registered all tagged smolt that had travelled down the fishway, the turbine or the spill. The fifth antenna was placed 10 km downstream from the power station (c. 33 180 m from the sea), while the last antenna was placed about 3500 m upriver from the sea. The fish were also tracked manually from shore at several occasions using an ATS receiver (RS2100) connected to a 4-element Yagi antenna. A Televilt RX8910 receiver was also used for fine scale positioning.

Based on registrations at the archival data-loggers in combination with manual tracking, the migration fates of individual smolts were assessed. Fish registered by antenna No. 1 and also registered downstream in the power station area, but not found in the smolt trap, were assumed to have taken the route through the turbine. Fish registered by antenna No. 3, but not found in the smolt trap, were believed to have taken the route through the spillways. Fish registered by antenna No. 4 were assumed to have survived passage through the turbine or the fishway. In the same way we assumed that the smolts registered by antenna No. 5 had passed the power station area unharmed. Fish registered by antenna No. 6 was counted as part of the successful migration.

RESULTS

After release of fish above the power station, the smolts showed various behaviour. Some fish left immediately downstream while others remained stationary for several days. One group (n=4) remained close to the release site over the whole study period, while the remaining smolts (n=23) moved downstream. Seven smolts stayed about 200 m further downstream in a slow flowing part of the river for the whole study period, while a third group (n=3) stopped (and stayed over the remaining study period) at the next lentic area, c. 500 m downstream from the release site. A total of 13 smolts reached the dam; of which two remained close upstream of the turbine intakes and 11 passed the power station area (nine through the turbine and two through the fishway).

A total of 15 smolts were released in the turbine intake, however, one of these never got registered on any of the antennas. Since it is unknown if the transmitter got damaged during the turbine passage, or if it was defect before release, this smolt was excluded from this study. One group (n=3) settled immediately downstream from the turbine outlet, whereas the majority of the smolts (n=10) were, when manually positioned, found in an area between 250 m and 2.5 km downstream the power station. Only one of these smolts made it to antenna No. 5, 10 km downstream from the power station.

Of the 13 fish that were released at the upper part of the fishway, five settled immediately downstream from the fishway, whereas a majority (n=6) of these smolts remained in a curved segment of the river about 250 m downstream from the power station. Two of the smolts released in the fishway got registered on antenna No. 5, 10 km downstream from the power station. None of the radio tagged smolts, regardless of release site, swam all the way to the sea.

Smolt fate and migration speed

Of the 30 radio tagged smolts that were released 1.1 km upstream from the power station, one smolt never got registered on any of the stationary antennas, nor was it found via manual tracking while two smolts were registered at very few occasions so it was impossible to determine the fate of these smolts. All these three smolts were excluded from further data analysis, which left 27 smolts released upstream from the power station. Of these, 16 smolts (59%) remained upstream of the dam (Figure 1) during the whole study period. 11 of the 27 smolts migrated downstream of the power station area. Nine of these (82%) swam through the turbine, while two (18%) swam through the fishway. None of the smolts swam through the spillway.

Adding both the nine smolts that swam through the turbine and the 14 smolts that were released in the turbine intake, gives a total of 23 smolts that swam via the turbine. Of these 23 smolts, eight (35%) settled downstream from the turbine outlet. Based on the fact that the three dead smolts released in the turbine intake all settled in the vicinity just downstream the turbine outlet, the eight fish above were considered as directly killed at their passage. Of the remaining 15 smolts that were not directly lost during their passage, only one got registered on antenna No. 5, 10 km downstream from the power station area, and was assumed to have passed the turbine unharmed. The other 14 smolts (93% of the 15 smolts) that did not reach antenna No. 5 were believed to have succumbed to indirect mortality at turbine passage. The overall turbine mortality was consequently estimated to 96% (22 of 23), including both direct and indirect losses, proportions of 36% and 64% of total mortality, respectively.

A total of 15 fish swam through the fishway. Two fish selected this route whereas the other 13 were released at the upper part of the fishway. Five of these (33%) settled downstream from the fishway, and were assumed to have died due to injuries caused by the passage through the fishway. Ten smolts survived the passage through the fishway, and did not show direct mortality. Of these smolts, two got registered on antenna No. 5, 10 km downstream from the power station area, and were assumed to have passed the fishway unharmed. The eight smolts that did not reach antenna No. 5 were believed to have succumbed to indirect mortality caused by the passage through the fishway. This would account for an indirect mortality of 80% during passage through the fishway.

The total direct losses for smolts passing the power station reservoir, the turbine and the fishway was estimated to 73%, while the total indirect mortality was estimated to 88% . The combined direct and indirect mortality for smolts passing the power station reservoir, the turbine and the fishway gives a total mortality of approximately 94% in the River

Åbyälven. Surprisingly, none of the smolts in the study made it all the way to the sea (Table 3).

After release, the tagged smolts showed various migration speeds. The migration time to the turbine intake at the power station 1.1 km downstream ranged from about 1 h - 19 h, which corresponds to a migration speed raging from about 1.1 km/h to 0.06 km/h. Still, one smolt migrated remarkably slower than the other smolts and did not pass the power station area until more than 16 days post release. The transport time for the water from the fish release site to the turbine intake was estimated to 1.5 hours. This speed is somewhat slower than the migration time for the fastest smolt, which suggests an active migration for this fish (Table 2).

Table 2. Migration time of smolt released upstream the power station area.

From release site to:	**Dam n= 11**		**Turbine intake n= 10**		**Passage n= 11**	
	Time	***Speed (km/h)***	***Time***	***Speed (km/h)***	***Time***	***Speed (km/h)***
Fastest	53 min	1,300	1 h, 9 min	0,957	3 h	0,367
Slowest	14 d, 20 h, 9 min	0,003	19 h, 29 min	0,056	16 d, 17 h, 31 min	0,003
Mean	1 d, 11 h, 52 min	0,031	6 h, 19 min	0,174	56 h, 12 min	0,020
Median	3 h, 26 min	0,320	4 h, 4 min	0,270	23 h 50 min	0,046

The losses of radio tagged smolts were illustrated using an analogue of the staggered-entry Kaplan–Meier formula (details in Pollock *et al*. 1989 and Serrano *et al.* 2009). Fish that ceased migrating and remained stationary in the same area until the end of the study were counted as mortalities.

Table 3. Migration success of radio tagged smolt (n=54) released at different sites.

Site	Passage success from release location				
Name	Distance from release site above dam (km)	Released above dam	Released in turbine	Released in fishway	Overall success
Release site above dam	0	27			27
Lake 1	0,17	23			23
Lake 2	0,51	16			16
Dam	1,05	13			13
Turbine intake	1,05	9	14		23
Fishway	1,09	2		13	15
Tailrace area	1,15	5	3	5	13
Antenna 4	1,35	6	10	6	22
Antenna 5	10,81	0	1	2	3
Sea	40,49	0	0	0	0

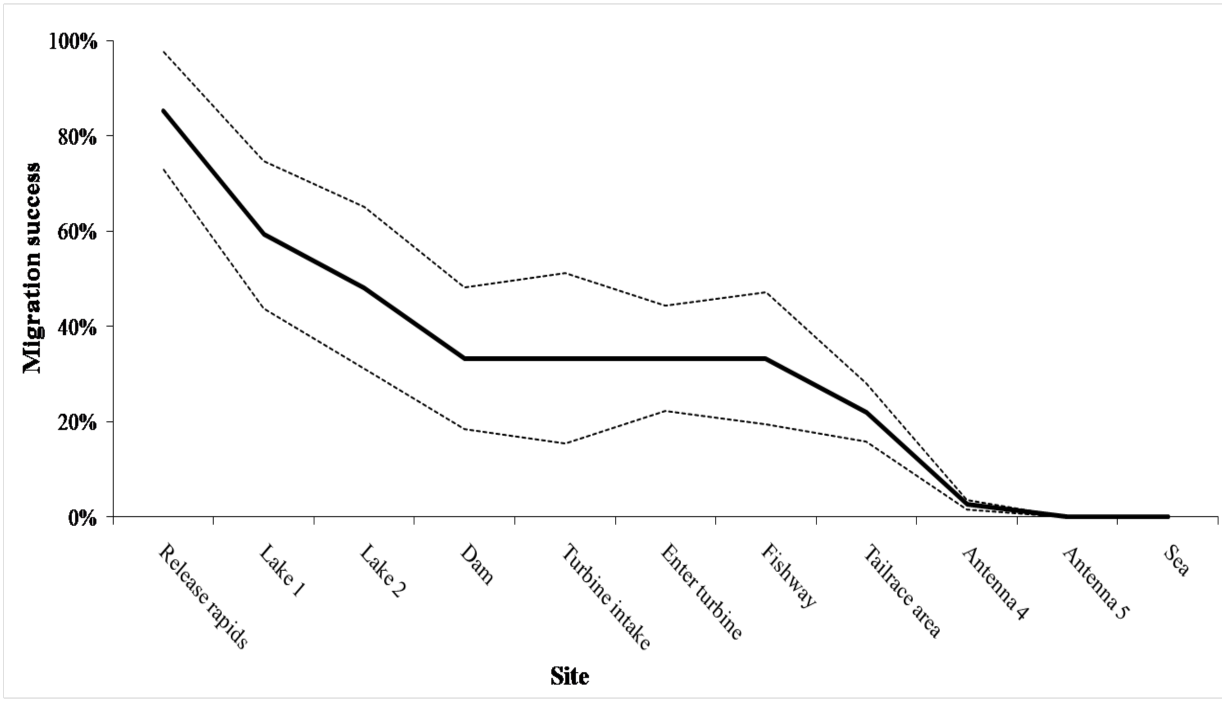

Fig 6. Kaplan–Meier cumulative survival estimates for radio tagged smolts (n=54) plotted together with 95% confidence intervals to various sites at River Åbyälven. For relation of sites and distance see table 3.

DISCUSSION

Losses due to passage through reservoirs

In my study 59% (16 of 27) of the radio tagged smolts released upstream from the power station remained upstream during the entire study period. This was not very surprising since high losses have been demonstrated for fish released in slow flowing waters, mainly due to increased predation and slower migration (Olsson *et al.* 2001). In a study at a comparable sized Swedish river (River Testeboån), Serrano *et al.* (2009) found that 37% of the radio tagged smolt remained in a lentic area 1 km downstream from the release site during the spring of 2006. The following year 65% of the radio tagged smolt remained in the same lentic area and many of the transmitters were detected in moving pike or found at the bottom of the river. Serrano et al (2009) assumed that the tagged smolts were victims of predation. A large proportion of the smolts in my study were, when manually tracked, found to remain stationary in pools of slow flowing water ideal for pike. It is therefore likely, as seen in previous studies, that a large proportion of the salmons have succumbed to predation.

Also, two drops in temperature occurred during the study period and this may have affected the smolts migration speed negatively. In a study by Rivinoja (2005) the lowest recorded downstream migration speed for smolts was associated with a temperature drop.

Other reasons for the fish reluctance to migrate downstream might be disturbances, loss of ability for downstream migration (desmoltification) or injuries due to the tagging process. However, since the tagging personnel were experienced on the procedures and all tagged smolts were in good condition at their release (about 10 h post tagging) the likelihood of negative tag effects should be very small in this study.

Power houses losses

In River Åbyälven, 82 % (9 of 11) of the radio tagged smolt swam through the turbine intake and 18 % (2 of 11) swam through the fishway. Rivinoja (2005) found that a majority of the migrating smolt in River Piteälven were surface oriented at depths of 1-3 m and that most of them followed the main flow in the highest water velocities with the same speed as the water. In River Åbyälven the mean flow through the turbine during the study period of the tagged smolts was 11.7 m^3s^{-1}, whereas the flow through the fishway during the same period was 0.5 m^3s^{-1}. Since the main bulk of water flows through the turbine (96%) this could explain why a majority of the smolt were guided in this direction.

A total of 23 smolts in this study went through the turbine. Of these smolts 35% (8 of 23) settled immediately downstream from the turbine outlet, and were considered to have succumbed to direct mortality caused by the turbine. Only one of the smolts got registered on the antenna halfway to the sea, whereas none of the smolts got registered on the antenna close to the sea. According to these results, the turbine in the Hednäs power station seems to be harmful to the fish and an alternate route for the downstream migrating smolts should be considered.

Compared to previous studies on power station induced smolt mortality, the direct mortality of 35% after turbine passage and the overall turbine mortality of 96% found in River Åbyälven seems to be higher especially in comparison with mortalities at other power stations equipped with Kaplan turbines (Table I). For instance, Rivinoja (2005) noted direct mortalities of c. 12% at the turbines in River Piteälven, while the overall mortality for smolts at power-station passage was estimated to c. 19%. Even lower mortality rates, about 6-8% was recorded by Calles *et al*. (in review) at two power stations in River Ätran. Nevertheless, in comparison to the power stations in these two studies, the power station in River Åbyälven is smaller, meaning a smaller turbine, that can cause a high loss rate. Loss rates of close to 100% were noted by CEATI (1982), while Serrano *et al*. (2009) noted losses of 60-75% in the similar sized River Testebo.

Losses due to passage through spillways and bypasses

In this study a total of 33% (5 of 15) of the smolts that took the route through the fishway remained immediately downstream from the fishway during the study period. These smolts were assumed to have been traumatized, injured or killed during their passage through the fishway, which would have made them unable to move further downstream.

Accelerating water is generally negative for the downstream migrating fish. The smolts may actually resist moving downstream and are therefore likely to hesitate at each weir in the fishway. Similar patterns have been observed in other studies (Kemp et al 2005) where smolts have been seen to avoid areas with rapidly accelerating flow.

These results indicate that the fishway in Hednäs is not ideal for downstream passage of smolts even if it seem to work fairly well for upstream passage of adult salmon.

Comparing mortalities

The mortality in the lentic area upstream from the power station was estimated to 59% (16 of 27), while the direct mortality in the turbine was estimated to 35% (8 of 23) and the direct mortality in the fishway was estimated to 33% (5 of 15). Taking these results into account, the dammed area upstream the hydropower facility with its predators seem to be what poses the greatest threat to the smolts during their downstream migration. Surprisingly, the mortality during passage through the fishway and the mortality during passage through the turbine showed little difference. It seems that it is almost as dangerous for the smolts to take the route through the fishway as to take the route through the turbine.

The combined direct and indirect mortalities of fish passing the turbine and the fishway, gives a total mortality of approximately 94% in River Åbyälven and none of the radio tagged smolts were registered on the lowermost antenna close to the sea. The rough estimate of the stream velocity in the River Åbyälven showed that the total time of transportation for the water 1.1 km upstream from the Hednäs power station to the sea was approximately 29 h. Earlier studies have shown signs of drifting behaviour of downstream migrating smolt, where the fish passively float with the stream (Moser et al.1991) Consequently, if the smolts in the River Åbyälven had been alive and drifting, they would have reached the sea about 29 h after release. Since the battery time of the radio transmitters was estimated to three weeks, the smolts should have registered on the antenna close to the sea if they were drifting or swimming actively with the current. Consequently, the lack of registered fish close to the sea was not due to expired batteries in the radio transmitters, but rather due to active swimming against the current, inability to migrate, (desmoltification) or mortality.

Possible management aspects

According to my results, both the power station turbine and the fishway in River Åbyälven caused losses of smolts. Consequently, an improved construction for downstream migration should be considered. One possibility would be to place the smolt trap at the top of the fishway and thereafter divert the fish downstream via an extended tube to areas downstream from the power station.

One thing to take into account is that it has been debated if salmon were historically able to pass upstream of the former waterfall where the power station is located today. This river section has possibly acted as a definitive or partial migration barrier for upstream migrating fish, meaning that the natural reproduction areas were restricted to sections downstream from the current power station site. Nevertheless, after installation of the fishway, new spawning habitats have become available which could favour the salmon population in the river if the downstream smolt migration could be secured. Therefore the downstream migration possibilities for smolts at the power station should be improved. Trials with different downstream guidance devices have started at the power station and hopefully a safe passage route can be provided in future.

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